PROBLEM SET 2: EARTHQUAKES AND SEISMOLOGY

EAS 3610/8803: Introduction to Geophysics

Assigned: 09/23/20 (Wed)
Due: 9/30/20 (Wed)

NAME: ______________________________

OTHERS CONSULTED: ______________________________

A note about your homework: Please be neat and organized! Once you have found a way to the answer, please rewrite it in an orderly fashion so that others can follow your steps, and put a box around your final solution, when appropriate. Include this page as the cover, show all of your work, and list all who helped with this set, including your instructors. Relative problem values are shown in [] at the beginning of the problem.

Seismic Waves

1. **[60]** Below are seismograms from a moment magnitude (M_W) 7.8 earthquake ($\lambda = -45.76°$, $\phi = 166.56°$, $Z = 12$ km) occurring almost due south of station KWAJ (located at: $\lambda = 8.80°$, $\phi = 167.61°$).

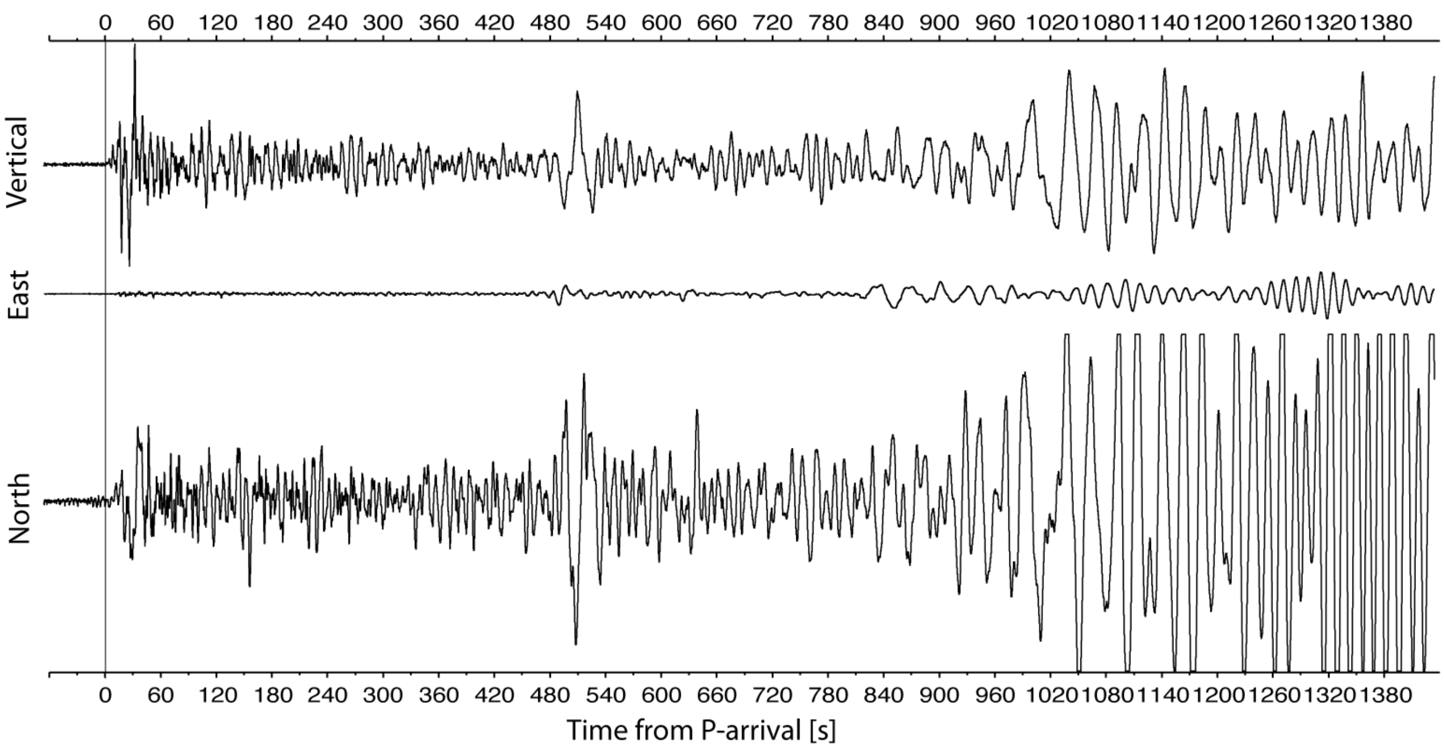

Figure 1: 3-component seismograms of the M_W 7.8 New Zealand subduction megathrust earthquake July 15, 2009 from station KWAJ. Recordings are normalized to same velocity (maximum ∼0.1 mm/s), and show the relative timing from the P-arrival. Later waves on the **North** record were 'clipped', meaning they were larger than the station could record.

(a) What is the distance between the station and the earthquake in both degrees (°) and km? You may simply consider the latitudinal distance, but you will need to convert from degrees to km. Note: If you do not already know how to do this consider the circumference in km. This is equal to 360° of latitude.

(b) Given that the earthquake began at 09:22:32 UTC, when did the P-wave arrive at KWAJ?

(c) Use a seismic travel-time table (like the one on figure 4.16 of Fowler and in lecture slides) to mark the onset of *P, PcP, S, ScS, SS, Love*, and *Rayleigh* waves on the figure.

(d) What type of wave and path do each of the above symbols correspond to?

(e) What are the dominant frequencies that you see in each the P, S, and surface waves (as determined from visual inspection–peak counting over time)?

(f) Why do you think so little energy (small wave amplitude) is coming in on the East component as compared to the North and Vertical?

Earthquake Location and Seismic Energy Radiation

These problems are in chapter 4 of "The Solid Earth" by Fowler.

2. **[10]** Problem 4.5: Micro-earthquake location in Turkey (use $\alpha = 5.6$ and $\beta = 3.4$ [km/s]).

3. **[10]** Problem 4.7: Earthquakes as green energy?

4. **[10]** Problem 4.8: Small vs. large earthquake energy.

Graduate Section Homework

Earthquake Deformation

Measurements of surface deformation can be used to identify the locking of a fault between earthquakes (called interseismic deformation). The simplest solution for such slip is an analytic equation describing fault parallel deformation rate in terms of the surface velocities, $v(x)$, in the fault-parallel direction at x distances away from an infinitely long vertically dipping strike-slip fault (Savage and Burford, 1973).

$$v(x) = (v_T/\pi)\tan^{-1}(x/w) \tag{1}$$

where $\pm v_T$ is the far-field fault-parallel velocity (+ for left-lateral motion), and w is the width of the locking section of the fault extending down from the surface. Below this depth, deformation is accommodated by ductile deformation of the lower-crust.

If the fault was completely unlocked (allowed to slip freely, $w = 0$), then the motion on either side would look like an immediate step.

$$v(x, w = 0) = (v_T/\pi)\tan^{-1}(x/0) \Rightarrow (v_T/\pi)(\pm\pi/2) \tag{2}$$

$$v(x, w = 0) = \pm v_T/2 \tag{3}$$

If the fault loaded for T_R years (the recurrence time) before it failed, the fault would slip, D, across the fault.

$$D = v_T T_R \tag{4}$$

Thus, the total motion, u_T, across the fault over a seismic cycle (one recurrence period) would appear as a simple step function.

$$u_T(x) = \pm\frac{v_T T_R}{2} \tag{5}$$

During an earthquake, if all locked strain is released, the deformation across the fault, u, will be the difference between the total motion and the interseismic deformation over the recurrence period.

$$u(x) = u_T(x) - v(x)T_R \tag{6}$$

$$u(x) = \pm\frac{v_T T_R}{2} - \frac{v_T T_R}{\pi}\tan^{-1}\frac{x}{w} = D(\pm\frac{1}{2} - \frac{1}{\pi}\tan^{-1}\frac{x}{w}) \tag{7}$$

Ultimately, the above model for elastic loading and strain release assumes that the rock undergoes no permanent (plastic) deformation on either side of the fault, which is a really good approximation for what we see in the field. We also can see with these models that the shape of deformation away from the fault varies by the total slip, and its distribution with depth.

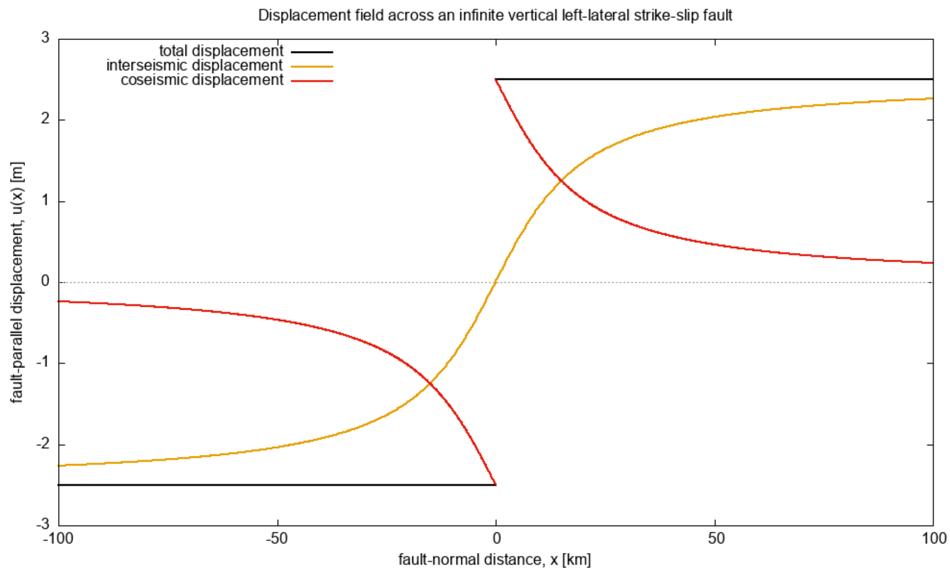

Figure 2: An example interseismic/coseismic/total-slip distribution for a theoretical fault aligned at $x = 0$, that was locked to 15 km depth, and loading at a rate of 5 cm/yr. Recurrence of a large earthquake every 100 years gives the total seismic-cycle displacement.

6. **[20]** Using the noisy 'data' in the file *http://geophysics.eas.gatech.edu/classes/Geophysics/HWs/displacement.xu*:
   (a) Plot the deformation field across the fault (located at $x = 0$).
   (b) Is this interseismic or coseismic deformation? (compare with Fig.2)
   (c) What is the total magnitude of displacement across the fault?
   (d) Is motion dextral (right-lateral), or sinistral (left-lateral)?
   (e) Using the above equations and your estimation of deformation, determine the approximate vertical width of the actively locking/slipping fault. To complete this, you may use a regression or other inversion algorithm, or you may more simply try a range of 'forward' models and determine which looks good.
   (f) Now, assuming that this fault accommodates earthquakes every 50 years, and that all plate-boundary motion is released in those earthquakes, what is the plate rate?

7. **[20]** Rupture on a buried fault:
   (a) Finally, because this model scales linearly with amplitude, it is possible to superimpose multiple slips to create a more complex/realistic model. Use the coseismic slip model above (equation 7), along with the knowledge that zero slip occurs between the surface and burial depth, h, to create a new analytic solution for uniform slip on a buried fault.
   (b) Plot this function using your solutions for D and w, but with $h = 2$ km. How does this compare to the surface rupture solution?